AN2531
Application note

Generating multicolor light using RGB LEDs

Introduction

The new high power and brightness RGB LEDs are going to be used in many different lighting applications as backlighting, general lighting systems, traffic signals, automotive lighting, advertising signs, etc. They are becoming popular mainly because it is possible to generate an easy multicolor light with special lighting effects and their brightness can be easy changed. On top of this, their long lifetime and small size make them the light source of the future.

This document describes how to drive RGB LEDs, how to calculate a power dissipation, how to design an over temperature protection, how to use a software PWM modulation and why over voltage protection should be implemented for this kind of application.

STEVAL-ILL009V1 reference board shown in *Figure 1* was developed in order to demonstrate this design concept. This board was designed for driving super high brightness multicolor RGB LEDs with current up to 700 mA per LED. The LED brightness and color can be very easy changed by potentiometers and an automatic color change mode continuously modulates the color of the LED to generate multicolor light. The LED over temperature protection is designed on this board and therefore the power delivered to the LED can be automatically limited to prevent LED overheating.

The STEVAL-ILL009V1 is a mother board assembled without LEDs. To evaluate light effect features, it is necessary to order a load board (additional board with assembled RGB LEDs). Two load boards are available for easy performance evaluation. The first one with the OSTAR® Projection Module (refer to *Chapter 12*, point *1*) has ordering code STEVAL-ILL009V3 and the second one with the Golden DRAGON® LEDs (refer to *Chapter 12*, point *2*) has ordering code STEVAL-ILL009V4. All technical information about these reference boards such as bill of materials, schematics, software, temperature protection and so on are described in the sections below.

Note: A new reference board STEVAL-ILL009V5 was designed in order to replace the former STEVAL-ILL009V1. The main reason why the new board was developed is to demonstrate a new DC/DC converter capabilities using the ST1S10 and new improved LED drivers STP04CM05 and STP08CP05. Thanks to the ST1S10 the size of the inductor is extremely decreased, efficiency improved and board size significantly reduced. The STEVAL-ILL009V5 reference design is described in Chapter 9.

Figure 1. STEVAL-ILL009V1 reference board

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1 Driving concept for RGB LEDs

RGB refers to the three primary colors, red, green, and blue. Different colors can be generated by controlling the power to each LED. In this application, the microcontroller provides three software PWM signals (principle is described below in *Chapter 4)* for LED drivers STP04CM596 so the color can be regulated.

The STP04CM596 is a high-power LED driver with 4-bit shift register designed for power LED applications. In the output stage, four regulated current sources provide 80-500 mA constant current to drive high power LEDs.

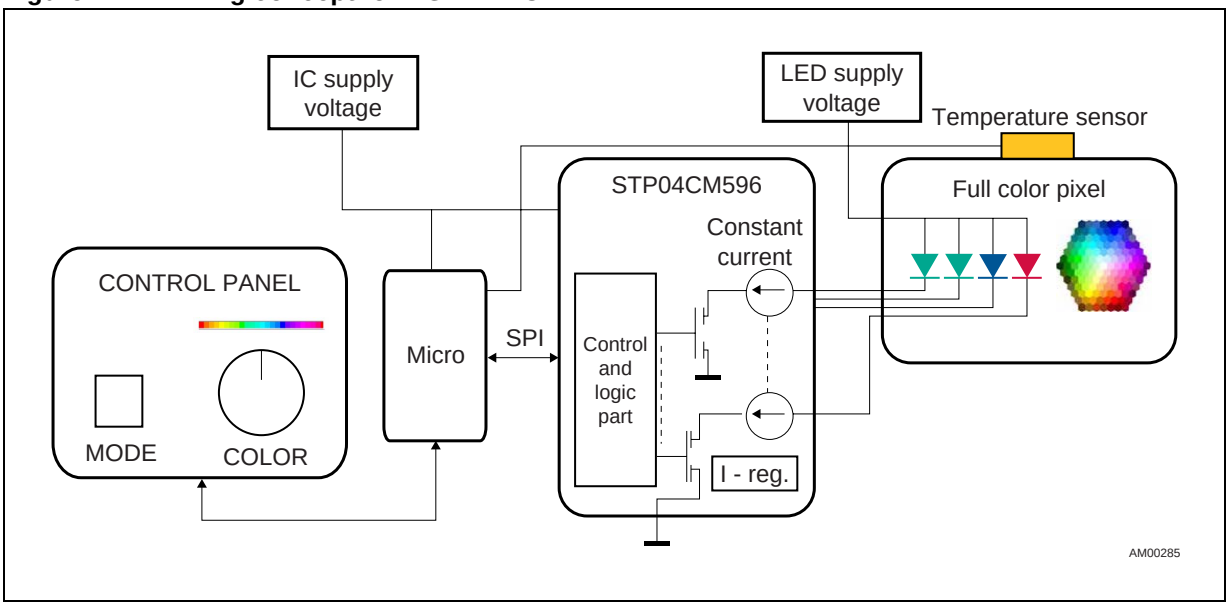
Figure 2 shows the driving concept for RGB LEDs using an STP04CM596 LED driver. The LED supply voltage is connected to anodes of RGB LED and LEDs cathodes are connected to the ground through constant current sources. The supply voltage value is very important due to the power dissipation on drivers (detail explanation is described in *Chapter 5*).

The value of the constant current is set by only one external resistor for all the four driver channels. The control unit in this application is a microcontroller, which sends data through serial peripheral interface (SPI) to the shift registers inside STP04CM596. The data are shifted bit by bit to the next drivers in a cascade with falling edge of the clock frequency (the maximum communication frequency for this drivers is 25 MHz). When all data are transmitted to the drivers through SPI, the micro sets latch input terminal (LE) pin “log 1" to rewrite the data to the storage registers and to turn on or off the LEDs. More details on timings and features are available in Application Note AN2141 (refer to *Chapter 12*, point *3*) and Datasheet of the STP04CM596 (refer to *Chapter 12*, point *4*).

Temperature protection is designed in order to protect LEDs and increase their lifetime. A sensor (STLM20) is assembled close to the RGB LEDs and informs the microcontroller about RGB LED temperature. If the temperature is above its limit, the microcontroller decreases LED brightness (LED power) through PWM signal.

An easy and user friendly hardware interface (potentiometers and buttons) was designed to demonstrate features such as color set, brightness regulation, mode changes, etc.

Figure 2. Driving concept for RGB LEDs



2 How to drive many LEDs

In several applications not only one RGB LED, but many of them must be driven. There are at least two possible ways to drive many RGB LEDs using the STP04CM596 LED driver, depending on the specific lighting application.

If the request is to control each RGB LED independently, a serial configuration (drivers in cascade connection) must be used as shown in *Figure 3*. The data are sent through all LED drivers via the SPI and then latched to the outputs. The main advantage is that current in each channel can be regulated by software PWM modulation, which in fact means color control of each RGB LED. The disadvantage of this solution is lower PWM resolution for a higher number of RGB LEDs, because it needs time to send data to all drivers. More information about this principle is described in *Chapter 4: Color control - software modulation*.

If the request is to build up a high power light with many LEDs of the same color, drivers can be connected in parallel as shown in *Figure 4*. Main advantages are a simpler solution and better PWM resolution, because only four bits are sent through the SPI and it takes a short time. Color is also regulated by software PWM signals as described in *Chapter 4*.

Note: It is also possible to mix serial and parallel configurations in order to provide several different colors with high lighting power. For example, two different colors using 10 RGB LEDs can be implemented using two STP04CM596 connected in series and five such blocks connected in parallel.

Figure 3. LED driver connection - serial configuration

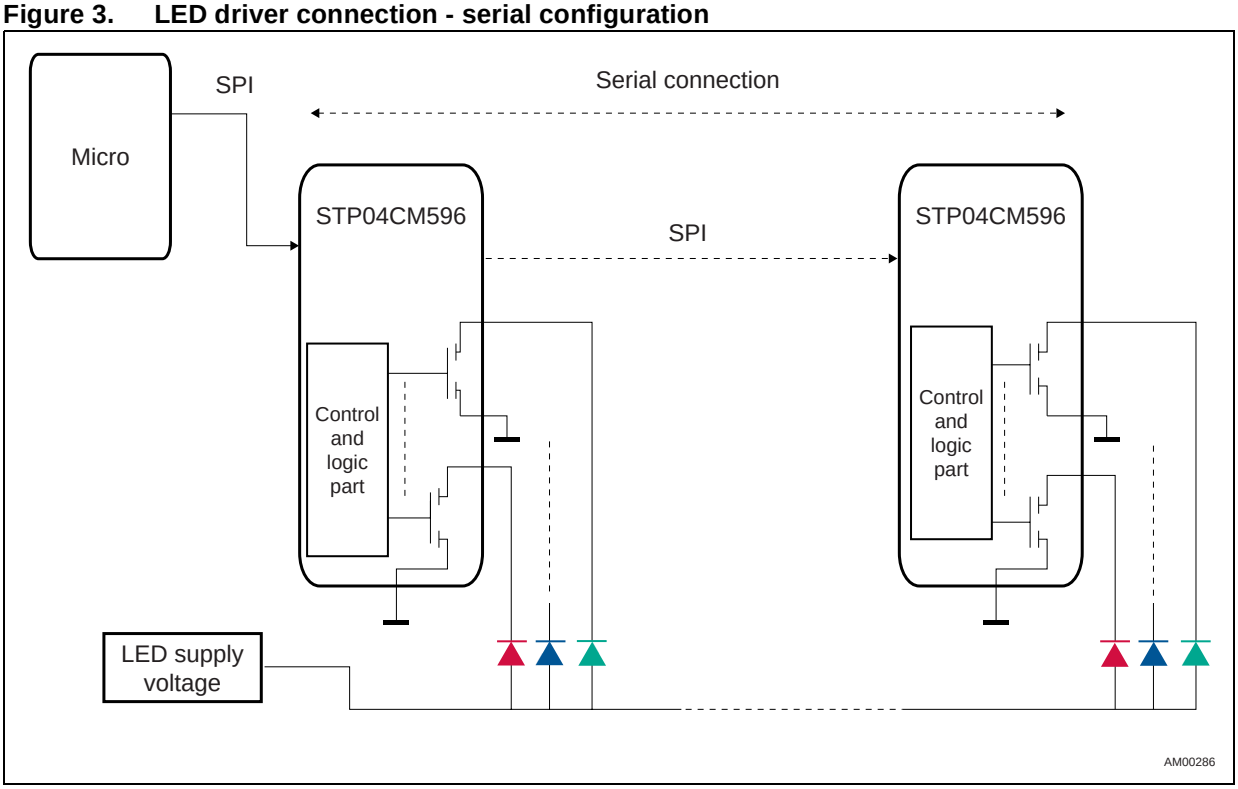
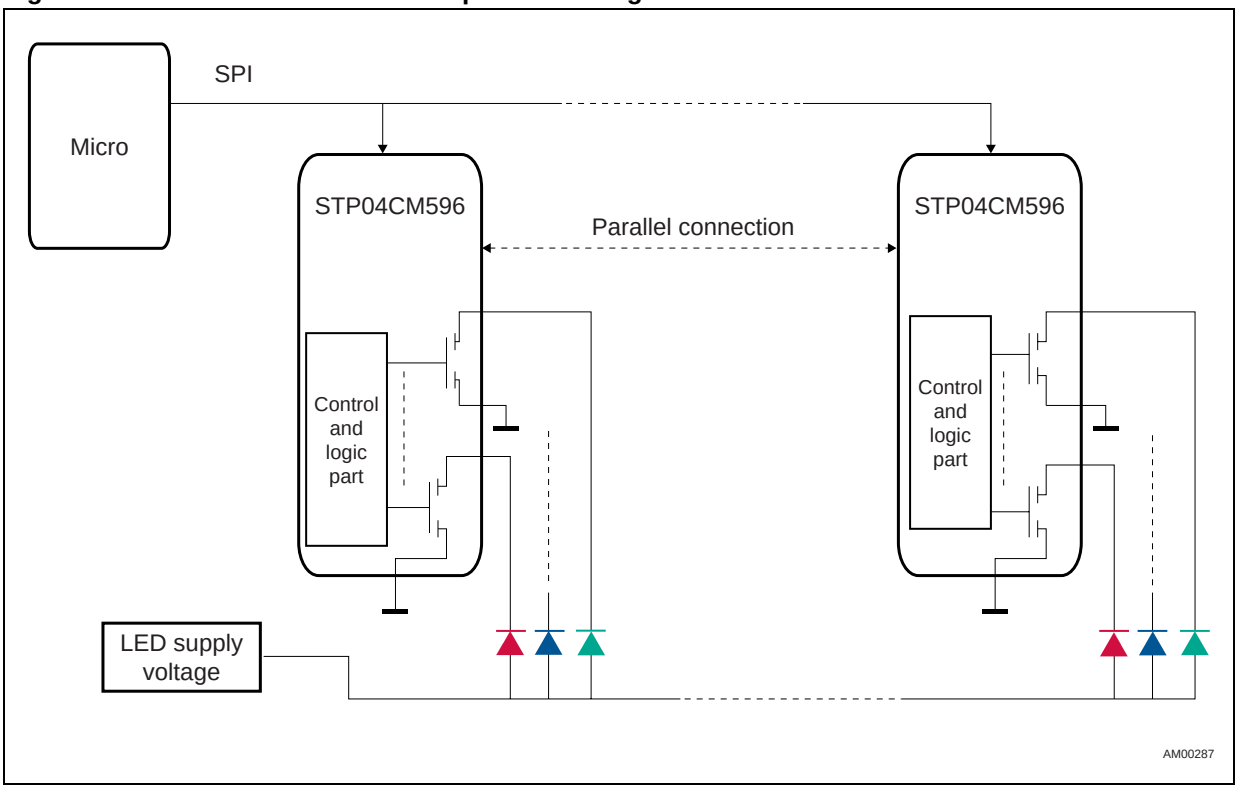


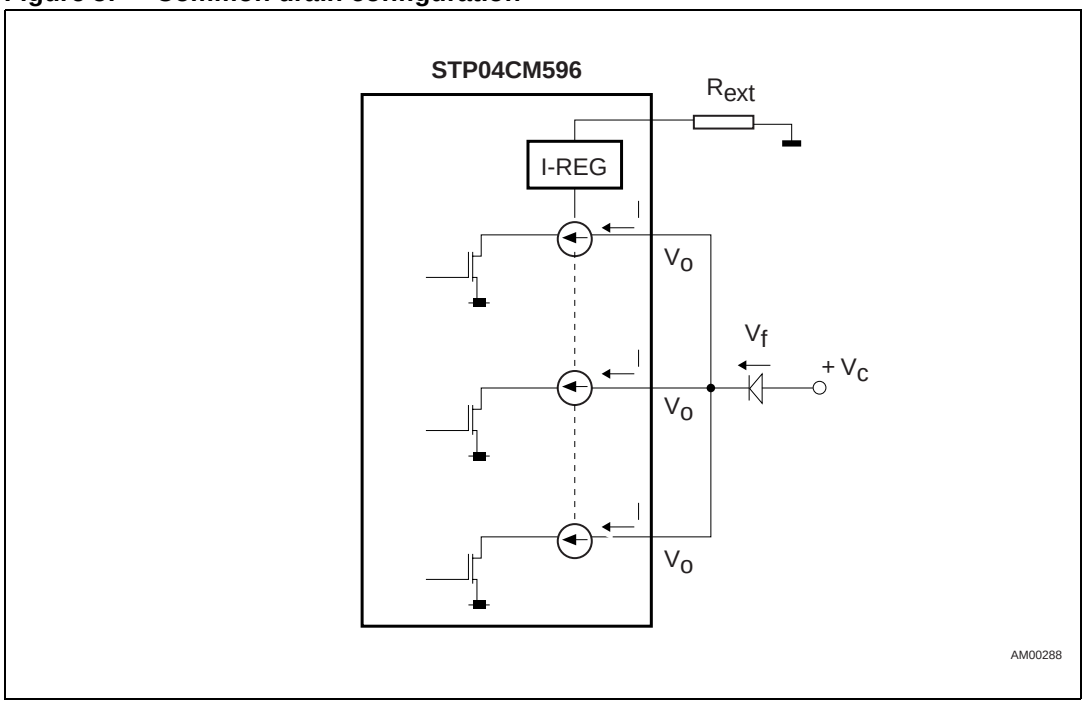
Figure 4. LED driver connection - parallel configuration



3 How to set high current for LEDs

The STP04CM596 is focused on driving high brightness and power LEDs and its output constant current can be set between 80 and 500 mA. In case a LED with even higher current is used, there is still a solution to control such LED using the STP04CM596. Thanks to a common drain configuration, the outputs can be connected together as shown in *Figure 5*. This increases the performance and current capability of this driver. This configuration allows driving the whole range of HB LEDs available on the market. For example, this principle is also used in the STEVAL-ILL009V1 presented in this application note, because the board has maximum current capability of 700 mA (2 channels x 350 mA).

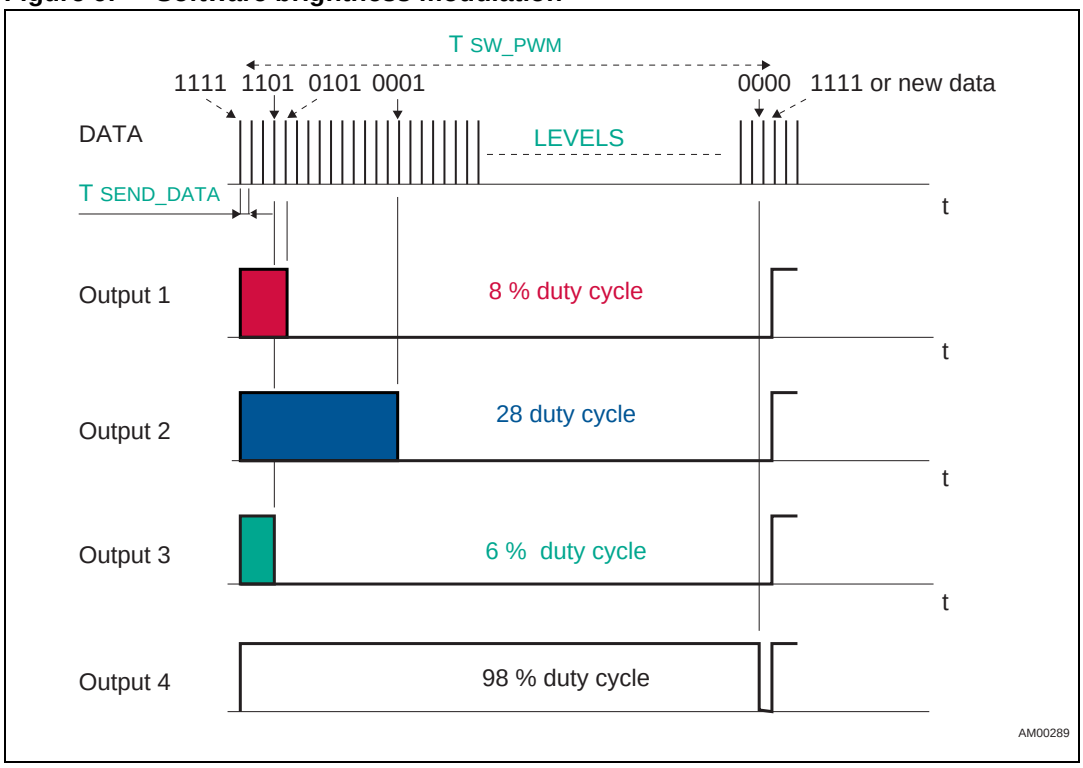
Figure 5. Common drain configuration



4 Color control - software modulation

Software control modulation allows adjusting power to each channel of the STP04CM596 driver (i.e. LED brightness). *Figure 6* explains the principle showing an example of how to set an 8% duty cycle for red, 28% duty cycle for blue, 6% duty cycle for green and 98% duty cycle for a fourth LED. For one complete dimming cycle, the microcontroller sends a certain number of “0”s and “1”s to each LED. First, the microcontroller sends four bits in “logical 1" (i.e. 1111b or Fh) to the driver in order to turn ON all the output channels. Then microcontroller sends the same data (1111) until an output should be turned OFF (depending on desired preset color). (Each bit of the 4-bit frame controlling its corresponding output.) In this example, it is output 3 with green LED (6% duty cycle required). From that moment, the microcontroller keeps sending 1101. In the next step the output 1 with red LED (8% duty cycle) should be turned OFF and so data frame changes to 0101. This frame is sent until output 2 with blue LED (28% duty cycle) should be turned OFF and when the frame 0001 is used. Finally, the output 4 with another LED (usually second green LED) is turned OFF with 98% duty cycle, which means than 0000 is being sent until maximum time for one cycle is reached. After that, the entire period for all outputs can start again.

Figure 6. Software brightness modulation



The resolution of the LED dimming defines how many steps are possible to change the duty cycle from 0% to 100% (e.g. 6-bit means 64 steps; 7-bit means 128 steps and so on). It is obvious that it is preferred to design the control signal with a resolution as high as possible, but several limitations should be taken into account. Limitations concern mainly the speed of the serial communication interface inside the microcontroller (SPI) and the general calculation power of the microcontroller. First, the general LED frequency should be selected. This value is recommended to be above 100 Hz in order to avoid flickering as at

100 Hz and above it is not detected by the human eye and is considered as a stable light. Using *Equation 1* and *Equation 2*, the resolution can be obtained as shown in *Equation 3*.

Equation 1

$$t_{SW_PWM} = \frac{1}{f_{SW_PWM}}$$

Equation 2

$$t_{SEND_DATA} = \frac{t_{SW_PWM}}{LEVELS}$$

Equation 3

$$LEVELS = \frac{1}{f_{SW_PWM} \times t_{SEND_DATA}}$$

In order to have a good resolution, the time for sending data (t_{SEND_DATA}) must be as short as possible. In an ideal case, this time takes into account the number of sent bits and the speed of the SPI clock (one bit is sent during one SPI period). As described in *Figure 6*, the number of sent bits corresponds to the number of driven LEDs, therefore in *Equation 4*, the number of driven LEDs is the same as number of bits sent (BITS = LEDS).

Equation 4

$$t_{SEND_DATA} = \frac{BITS}{f_{SPI_CLK}} = t_{SPI_CLK} \times BITS$$

The maximum number of used LEDs is (assumption BITS = LEDS):

Equation 5

$$LEDS = \frac{1}{f_{SW_PWM} \times t_{SPI_CLK} \times LEVELS}$$

Note: The above calculation is only valid only when the data are sent to the driver through the SPI without any delay. This means the data (BYTES) are sent thought the SPI and at the end of this communication the next data (BYTES) are immediately sent, etc.
In case the data are sent through the SPI and then microcontroller executes some other instructions (checking temperature, checking ADC in order to set next PWM signal, etc.), the period (t_{SEND_DATA}) for sending data is longer and it decreases the real maximum resolution.

5 Power dissipation

The maximum power dissipation can be calculated with ambient temperature and thermal resistance of the chip. The thermal resistance depends on the type of package and can be found together with maximum junction temperature in the datasheet. The maximum allowable power consumption without a heatsink is calculated as follows:

Equation 6

$$P_{dmax} = \frac{T_{jmax} - T_a}{R_{thja}}$$

$P_{d\ max}$ ……. maximum power dissipation [W]

T_a …… ambient temperature [°C]

$T_{j\ max}$ ……. maximum junction temperature [°C]

R_{thja} ……. junction to ambient thermal resistance [°C/W].

A high power RGB LED is in fact driven in linear mode with STP LED driver family. The current flowing through each channel of the LED driver is constant and so power dissipation depends on the voltage on each channel, which is the difference between the supply voltage (DC bus) and the forward voltage drop on the LEDs. Therefore it is recommended to keep the supply voltage as low as possible, but always above the maximum LED forward voltage. *Figure 7* shows the RGB LED connection to the driver. Total power dissipation in this case is calculated using the following equation:

Equation 7

$$P_{tot} = I*(V_C - V_{f_red}) + I*(V_C - V_{f_blue}) + 2*I(V_C - V_{f_green})$$

P_{tot}…….power dissipation on chip [W]

I……constant LED current set by external resistor [A]

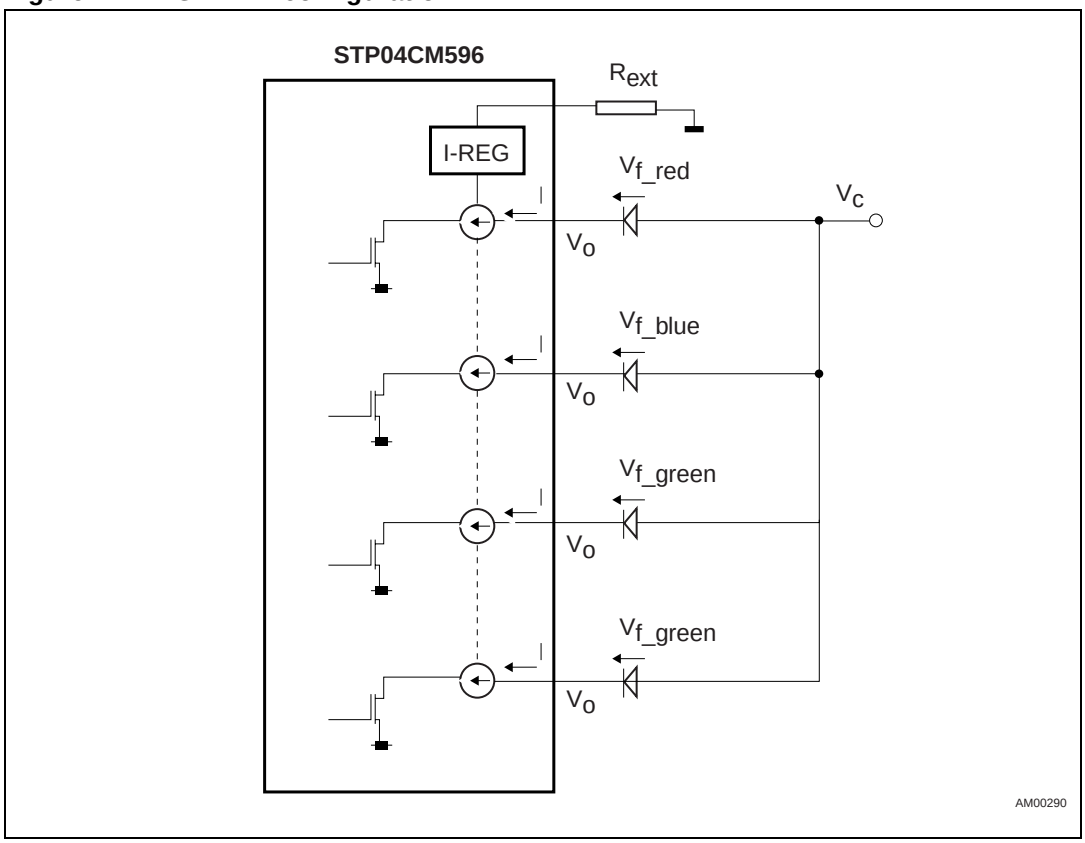
V_c……LED supply voltage [V]

V_{f_red}……red LED forward voltage [V]

V_{f_blue}……blue LED forward voltage [V]

V_{f_green}…….green LED forward voltage [V].

Figure 7. RGB LED configuration



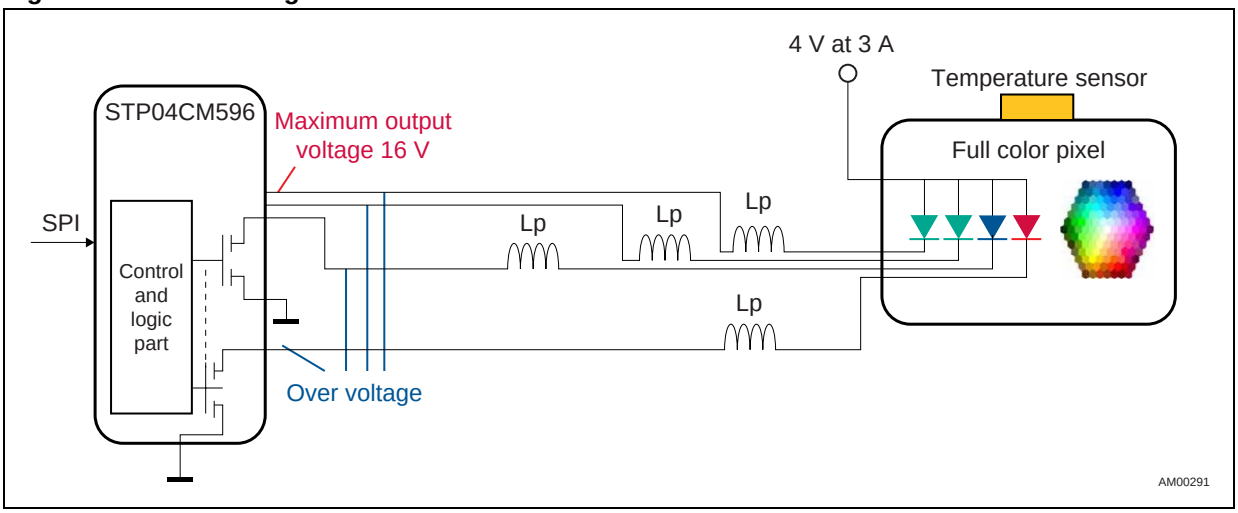
Note: Red, blue and green LEDs have different forward voltages (refer to Chapter 2). In general, the red LED has a lower forward voltage and therefore the power dissipation on the red LED channel is the highest. There is quite simple way to decrease this power dissipation by using a serial resistor with the red LED. Calculation example is shown in Section 10.1 and 11.1.

6 Over voltage protection

6.1 Description

The maximum voltage on the output channels of STP04CM596 is 16 V. Any wire or PCB track connection between LEDs and STP04CM596 driver presents a parasitic inductance as shown in *Figure 8*. This parasitic inductance produces voltage spikes on the outputs of the driver when the driver is turning off the LEDs and it can be dangerous for the STP04CM596 as it can exceed the maximum output voltage rating. Generally, higher current and higher parasitic inductance (long cable) means higher voltage peaks. Therefore over voltage protection is very important for high brightness LEDs in case of long connections between the driver and LEDs.

Figure 8. Over voltage on STP04CM596



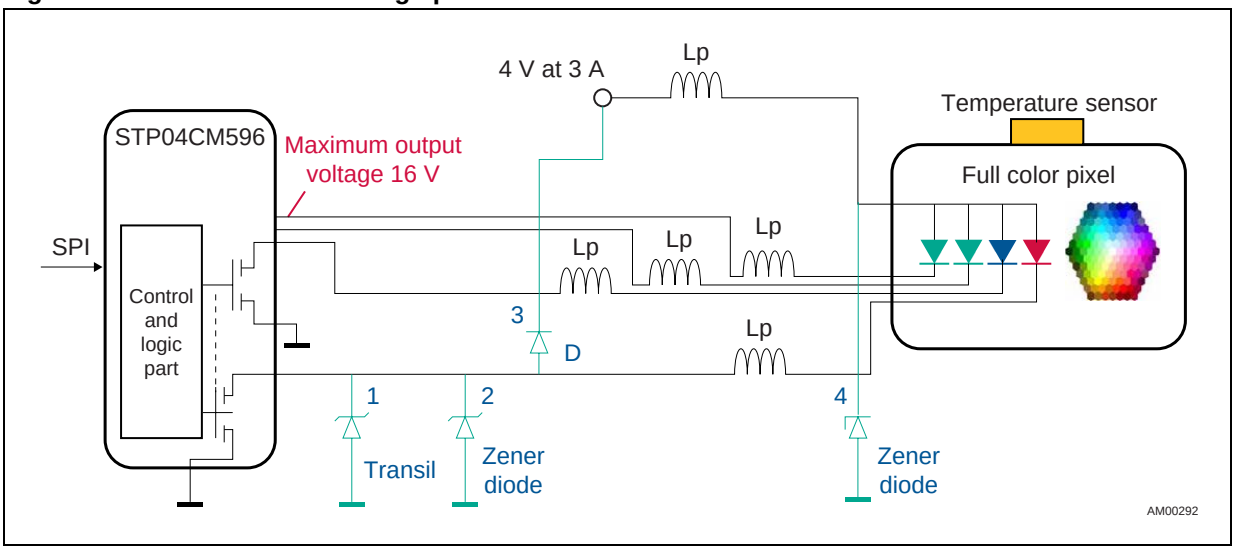
6.2 Type of solutions

Figure 9 shows possible types of over voltage protection. The first solution proposes a Transil™ or a Zener diode connected between each channel of the LED driver and ground. Unidirectional Transils with break down voltage lower than 16 V such as the SMAJ Transil family (refer to *Chapter 12*, point *5*) can be used.

The second solution proposes to use a standard diode or Schottky diode as a freewheeling diode. Diodes are connected between the LED supply voltage (DC bus) and driver's channel and so limit the voltage on the channels.

The third solution is the most cost effective and uses only a single Zener diode which protects all channels. It can be used only if the connection between the LED driver and LED cathodes is a quite short and if the connection between LED supply voltage and anodes is long. This protection limits over voltage peaks on LED anodes.

Figure 9. Possible over voltage protections

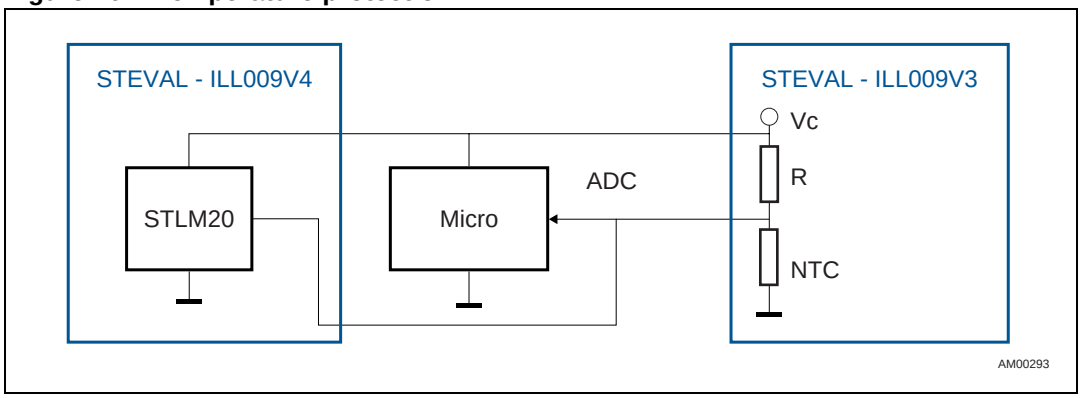


7 LED temperature protection

The STEVAL-009V1 was designed for high power RGB LEDs with a nominal power even higher then ten watts. As the lifetime of LEDs significantly decreases with temperature, the proper temperature management must be implemented to check and limit its maximum values.

Two different temperature protections are used in this design as shown in *Figure 10* - the STLM20 temperature sensor and NTC (negative temperature coefficient) resistor. The STEVAL-ILL009V3 uses an NTC resistor directly assembled on the aluminum LED board (OSTAR projection module). The STEVAL-ILL009V4 has assembled the STLM20 temperature sensor in the middle of LEDs on the PCB. The microcontroller checks the voltage from the sensors and sets the correct output PWM signal on the OE pin of the LED drivers. The microcontroller can increase the duty cycle of the PWM signal (0% duty cycle is max bright and 100% duty cycle is no bright) or can turn OFF the RGB LED if over temperature occurs. Software implementation is up to designers. Temperature protection calculation using the STLM20 or NTC is presented in *Chapter 8.5.2*.

Figure 10. Temperature protection



8 STEVAL-ILL009V1 reference board

STEVAL-ILL009V1 reference board shown in *Figure 1* was designed to demonstrate how high power and high brightness RGB LEDs can be driven and to confirm the principles described in the paragraphs above.

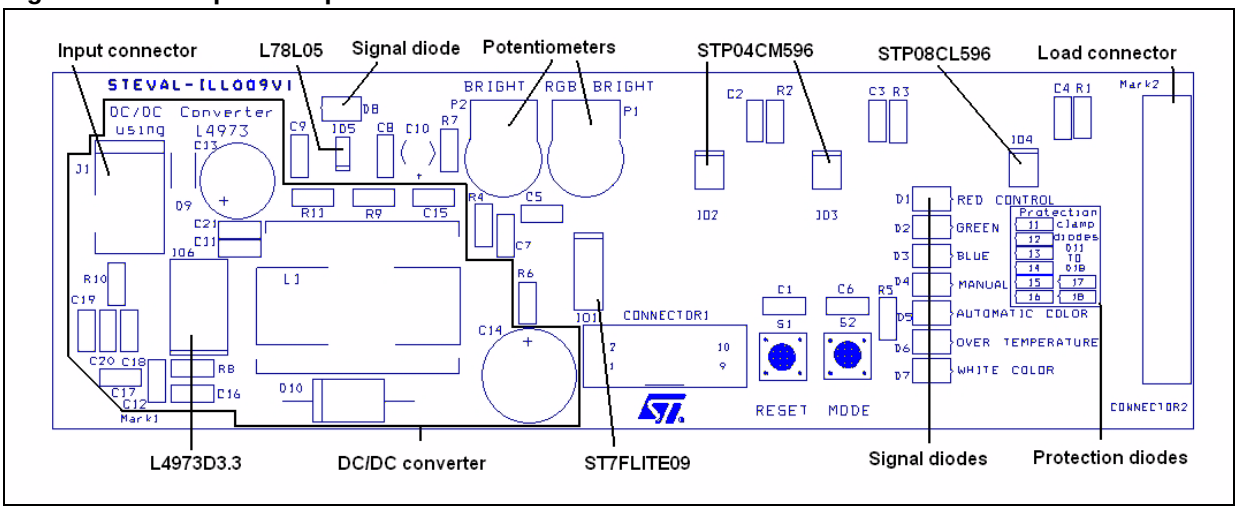
This board has the following main features:

- Different LEDs as a load can be used (additional boards connected through 30 pin connector)
- 8 LEDs with 350 mA can be driven (e.g. Golden DRAGON module - STEVAL-ILL009V4)
- 4 LEDs with 700 mA can be driven (e.g. OSTAR module - STEVAL-ILL009V3)
- LED over temperature protection using STLM20 or NTC resistor
- LED temperature limit set by software
- 3 A at 4 V DC/DC converter using L4973D3.3 for user friendly input (8 - 30 V)
- Color regulation (manual / auto)
- Brightness PWM regulation with 64 levels using OE pin (dimming all LEDs)
- Red, Green, Blue individual tuning
- White color preset mode
- LED frequency = 100 Hz
- 64 levels of brightness for each LED with software color control
- 262144 color variations (64 x 64 x 64)
- SW startup implemented (200 ms)
- Over voltage protection implemented using clamp Schottky diodes (BAT46)
- 6 different light MODES available
- Input over voltage protection done by Transil (SMAJ33A)
- Over temperature signalization
- I_{CC} connector for SW evaluation and change.

8.1 General description

Figure 11 shows components position on the STEVAL-ILL009V1. On the left side there is DC/DC converter with L4973D3.3 (ref. to *Chapter 12*, point *6*) with power capability 3 A at 4 V. The input voltage range is from 8 to 30 V and it is connected through input connector. The L78L05 (ref. to *Chapter 12*, point *7*) provides 5 V supply voltage for the microcontroller and LED drivers (signal diode D8 is used to show connected power). Potentiometers P1 and P2 are used to set brightness for all LEDs or tuning each of them separately. High power RGB LEDs are driven by STP04CM596 and STP08CL596 is used to control signal LEDs (D1-D7) which are implemented to show which of the several lighting modes is currently set. 30 pins load connector provides better flexibility, because different types of LEDs can be connected to the same board. As an example two load boards with LEDs were designed - STEVAL-ILL009V3 and STEVAL-ILL009V4.

Figure 11. Components position on the STEVAL-ILL009V1



8.2 Getting started

Getting started chapter briefly describes how to use the STEVAL-ILL009V1 as a step by step guide in order to quickly start with the evaluation.

1. Connect LED board to the STEVAL-ILL009V1 reference board using the 30-pin load connector2. STEVAL-ILL009V3 or STEVAL-ILL009V4 is LED boards.
2. Connect the supply voltage between 8 to 30 V on the board using J1 connector. **The power capability of the adapter must be higher then 14 W** in order to have enough energy for the application.

Note: The maximum channel current is set to 350 mA and so the LEDs and driver power consumption is P_{LEDout} = 4V x 0.35 mA x 8 = 11.2 W. The efficiency of the DC/DC converter is approximately 80 % (P_{LEDin} = 13.44 W). Considering the microcontroller and LED drivers themselves must be also supplied (consumption is less than 0.5 W) the total consumption is ~14 W and therefore the power capability of the adapter must be higher then 14 W in order to have enough energy for the application.

3. If the application is supplied, the green LED (D8) is lighted ON. It shows that there is a supply voltage for the micro and the drivers. Also LED D5 is turned ON at the start-up as the Automatic Color Control mode is set. Color automatically changes from blue to green, green to red and red to blue. During this mode, the brightness of all LEDs can be changed by potentiometer P2, but the function of the potentiometer P1 is disabled in this mode.
4. Press the button (S2) to change the mode. The next mode is White Color Control mode. LED D7 is turned ON. The brightness of all LEDs can be changed by potentiometer P2 and the function of the potentiometer P1 is disabled in this mode.
5. Press the button (S2) to set the next mode. It is Red Color Control mode. In this mode the brightness for the Red LED can be changed by potentiometer P1. There are 64 levels of brightness implemented. LED D1 is turned ON and the potentiometer P2 has the same function as in point 4 - changing the brightness of all LEDs.
6. Press the button (S2) to set brightness for the Green LED. In this mode the brightness for the Green LED can be changed by potentiometer P1. LED D2 is turned ON. The potentiometer P2 has again the same function - changing the brightness of all LEDs.

Note: The brightness level of the RED light is set by previous mode and stored in the memory and so the effect of the GREEN color is added to the RED one.

7. Press the button (S2) to set brightness for the Blue LED. In this mode the brightness for the Blue LED can be changed by potentiometer P1. LED D3 is turned ON. The potentiometer P2 has the same function - changing the brightness of all LEDs.

Note: The brightness levels of the RED and GREEN lights were set by previous modes and stored in the memory and so the BLUE color is added to the RED and GREEN one.

8. The next mode (press button S2) is a Manual Color Control mode. It means the color can be set as requested (going through predefined R-G-B curve) by the potentiometer P1. LED D4 is turned ON. The potentiometer P2 has the same function - changing the brightness of all LEDs.
9. **During all modes described above, LED temperature control is implemented.** If over temperature occurs, the brightness of all LEDs is decreased by PWM signal on the general OE/ pin (64 levels). The temperature is checked every 2.55 s and if it is still above the limit, the duty cycle of PWM is further increased (OE/ pin has a “not output enable” function, i.e. higher the duty cycle lower the brightness and vice versa). The maximum temperature on the LED board is set to 50 °C for the Golden DRAGON LEDs and 72 °C for the OSTAR Projection module. Note that the higher temperature limit can be very easily set by software.
10. **How to demonstrate over temperature protection?** Set full brightness by potentiometer P2 in White Color Control mode and wait approximately 3 minutes with STEVAL-ILL009V3 (board with heatsink) or 1½ minutes with STEVAL-ILL009V4 (board without heatsink). Temperature on LEDs is increased and if the over temperature is detected, LED D6 is turned ON and the PWM duty cycle is increased and the brightness decreased overcoming the potentiometer settings. The temperature of LED board then should go down and if no over temperature is detected after the period of time, the duty cycle is decreased again and normal operation is resumed.

8.3 Schematic description

The STEVAL-ILL009V1 reference board schematic diagram is shown in *Figure 12* and *Figure 13*. It is divided into two figures for easier understanding.

Figure 12 shows the components needed for LED driving. Resistors R2 and R3 set a maximum constant current 350 mA for each output channel of the STP04CM596. Thanks to this configuration, eight high brightness LEDs with the forward current 350 mA or 4 LEDs with the forward current 700 mA (two outputs are in parallel) can be driven. The STP08CL596 drives signal LED diodes with the constant current set to approximately 8 mA. The signal coming from the NTC resistor or STLM20 temperature sensor assembled in additional board (load boards) is filtered by a low-pass filter using capacitor C7 and resistor R6.

Figure 13 shows the power sources for the application. A 12W DC-DC SMPS converter is built on L4973D3.3 and design calculations are described in the datasheet (ref. to *Chapter 12,* point *6*) or in the AN938 (ref. to *Chapter 12*, point *8*). The L78L05 is a linear voltage regulator with output voltage set to 5 V used for microcontroller and drivers supply.

Figure 12. STEVAL-ILL009V1 schematics - LED drivers part

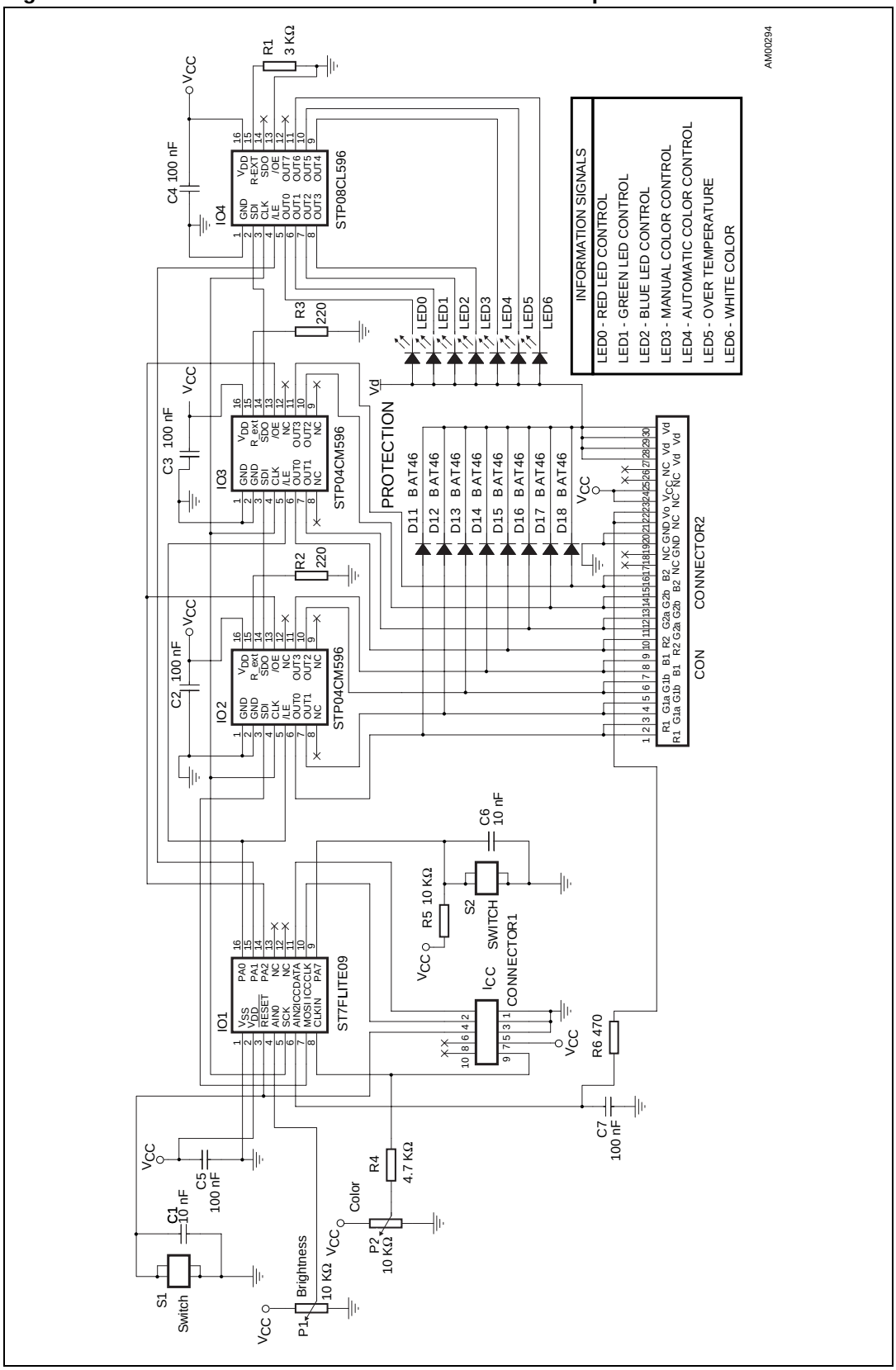
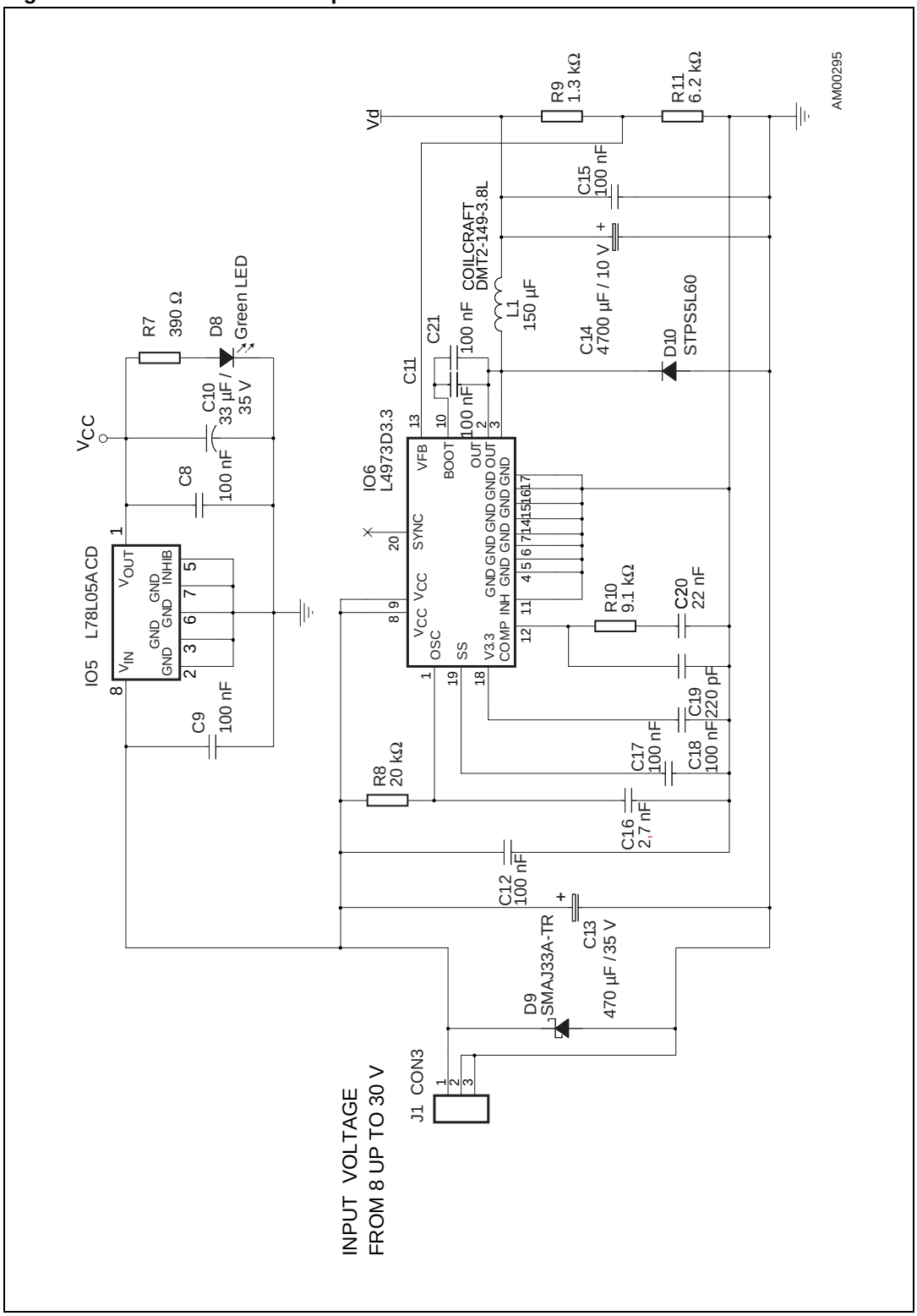


Figure 13. STEVAL-ILL009V1 power sources schematic



8.4 Bill of material

Table 1. BOM - STEVAL-ILL009V1

Item	Qty	Reference	Part	Note	Ordering code
1	1	CONNECTOR1	I_{CC}	10 PIN	
2	1	CONNECTOR2	CON	30 PIN	
3	2	C1, C6	10 nF	Ceramic SMD1206	
4	13	C2, C3, C4, C5, C7, C8, C9, C11, C12, C15, C17, C18, C21	100 nF	Ceramic SMD1206	
5	1	C10	33 µF / 35 V	Electrolytic	
6	1	C13	470 µF / 35 V	Electrolytic	
7	1	C14	4700 µF / 10 V	Electrolytic	
8	1	C16	2,7 nF	Ceramic SMD1206	
9	1	C19	220 pF	Ceramic SMD1206	
10	1	C20	22 nF	Ceramic SMD1206	
11	7	D1, D2, D3, D4, D5, D6, D7	Red LED	SMD LED 1206	
12	1	D8	Green LED	SMD LED 1206	
13	1	D9	SMAJ33A-TR	ST - Transil	SMAJ33A-TR
14	1	D10	STPS5L60	ST - diode	STPS5L60
15	8	D11, D12, D13, D14, D15, D16, D17, D18	BAT46	ST - Schottky diode	BAT46JFILM
16	1	IO1	ST7FLITE09	ST - microcontroller	ST7FLITE09Y0M6
17	2	IO2, IO3	STP04CM596	ST - LED driver	STP04C596XTTR
18	1	IO4	STP08CL596	ST - LED driver	STP08CL596TTR
19	1	IO5	L78L05	ST - voltage regulator	L78L05ACD
20	1	IO6	L4973D3.3	ST - DC/DC converter	L4973D3.3
21	1	J1	CON3	Input connector	
22	1	L1	150 µH	Coilcraft inductor	DMT2-149-3.8L
23	2	P1, P2	10 kΩ	Pot. with axis	
24	1	R1	3 kΩ	SMD resistors 1206	
25	2	R2, R3	220	SMD resistors 1206	
26	1	R4	4.7kΩ	SMD resistors 1206	
27	1	R5	10 kΩ	SMD resistors 1206	
28	1	R6	470 Ω	SMD resistors 1206	
29	1	R7	390 Ω	SMD resistors 1206	
30	1	R8	20 kΩ	SMD resistors 1206	
31	1	R9	1.3 kΩ	SMD resistors 1206	
32	1	R10	9.1 kΩ	SMD resistors 1206	
33	1	R11	6.2 kΩ	SMD resistors 1206	
34	2	S1, S2	Switch	Switch	

8.5 Design calculation

8.5.1 LED supply voltage

In order to have low power dissipation on STP04CM596 LED drivers it was chosen to have LED supply voltage 4 V. The maximum current flowing through LEDs is 2.8 A (0.35 A x 8). Therefore L4973D3.3 DC-DC converter with output power capability 12 W - 4 V at 3 A was designed. The output voltage is calculated in *Equation 8*:

Equation 8

$$V_F = V_d \frac{R_{11}}{R_{11} + R_9}$$

Where:

V_F..... Converter feedback input - > 3.3 V
V_d ..... LED supply voltage --> 4 V

From *Equation 9* below resulting R9 = 1300 Ω (R11 is chosen 6.2 kΩ)

Equation 9

$$R_9 = R_{11} \frac{V_d - V_F}{V_F} = 6.2 \times \frac{4 - 3.3}{3.3} = 1.3K\Omega$$

8.5.2 Temperature protection

Using STLM20 temperature sensor

The STLM20 is a precise analog temperature sensor for low current applications. It operates over a –55 to 130 °C (Grade 7) or –40 to 85 °C (Grade 9) temperature range. The power supply operating range is 2.4 to 5.5 V. The accuracy of the STLM20 is ± 1.5 °C, at an ambient temperature of 25 °C. More information about the STLM20 is described in the datasheet (refer to *Chapter 12*, point *9*).

A simple linear transfer function, with good accuracy near 25 °C is expressed as:

Equation 10

$$V_o = -11.79mV/°C \times T + 1.8528V = -11.79 \times 10^{-3} \times 50 + 1.8528 = 1.263V$$

If the sensor temperature is 50 °C, the output voltage is 1.263 V (resulting from *Equation 10*). This analog voltage is then sensed by the 8-bit ADC with an input voltage range 0 to 5 V inside the microcontroller. This number is used by software to limit the temperature. The software also includes the table with pre-calculated integer numbers for temperatures of 60, 70 and 80 °C and so it is very easy to change temperature limits (see *Table 2*).

Note: Temperature limit set to 50 °C was chosen in order to demonstrate temperature limitation feature (it takes a long time to heat LEDs assembled on heatsink to high temperature). In final application higher temperature limit can be set according the LEDs used and their maximum operating temperature.

Table 2. Temperature limit setting using STLM20

Temperature [°C]	Sensor voltage [V]	ADC integer number
50	1.263	65
60	1.145	59
70	1.027	53
80	0.909	47

Using NTC resistor on the OSTAR module

Figure 10 shows a voltage divider using resistor R and NTC resistor to obtain a voltage in function of temperature. Resistor was chosen R = 4700 Ω and the calculated sensor voltage and ADC integer number according used NTC resistance for 50, 60, 70 and 80 °C using following equation:

Equation 11

$$V_{sensor} = V_{CC} \times \frac{NTC}{NTC + R}$$

Note: V_{CC} = 5 V.

The software also includes a look-up table with pre-calculated integer numbers for 50, 60, 70 and 80 °C and so it is very easy to change the temperature limit (see *Table 3*).

Note: The software implemented in the STEVAL-ILL009V1 sets the integer number to 65. This means that the temperature is limited to 50 °C for the board using STLM20 (STEVAL-ILL009V4) and to 72 °C for the board using OSRAM module with NTC resistor (STEVAL-ILL009V3).

Table 3. Temperature limit setting using NTC

Temperature [°C]	NTC resistance [kΩ]	Sensor voltage [V]	ADC integer number
50	3.5	2.13	109
60	2.5	1.73	89
70	1.7	1.32	68
80	1.3	1.08	55

8.5.3 SW PWM frequency calculation

In order to have a correct PWM signal on each output, it is necessary to always send data after the same time. This means that the t_{SEND_DATA} value must be always same (as explained in *Figure 6*). The ST7FLITE09 microcontroller has a 12-bit auto-reload timer used to generate a constant time base for data sending. It is set to 156 µs and so after each 156 µs period, the data are sent. Resolution is 6 bits and therefore 64 brightness levels are available. One period of the SW dimming signal is:

Equation 12

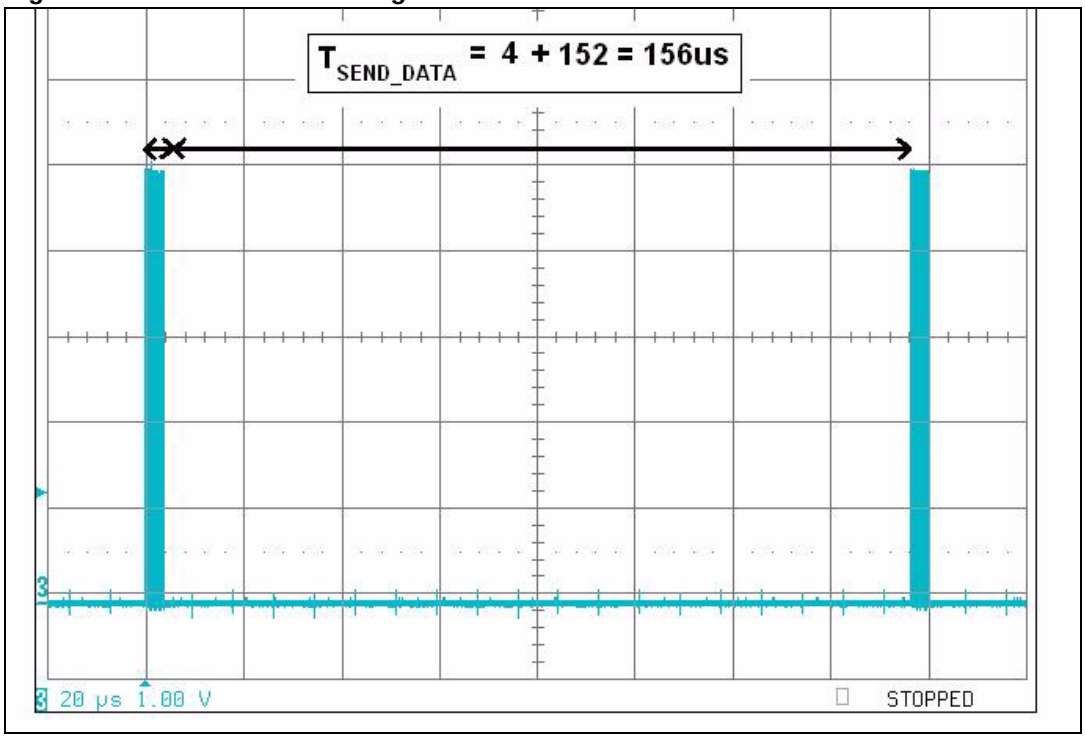
$$t_{SW_PWM} = LEVELS \times t_{SEND_DATA} = 64 \times 156 \times 10^{-6} = 9.984ms$$

Equation 13

$$f_{SW_PWM} = \frac{1}{t_{SW_PWM}} = \frac{1}{9.984 \times 10^{-3}} = 100.16\ Hz$$

Note: Some applications often require a PWM frequency higher than 100 Hz (even 100 Hz is observed as a still color without any flickering) and also a PWM resolution higher than 6-bit (64 LEVELS). Figure 14 shows the waveform of SPI clock frequency that explains why the 6-bit resolution of the PWM signal and frequency 100 Hz was designed. The time for sending data is 156 µs, but the SPI communication takes only 4 µs (8 bit times 0.5 µs - SPI clock is 2 MHz) and the rest (152 µs) is software execution due to many features as temperature protection, lighting modes, ADC reading, etc. As shown, there is still room to improve the SW PWM resolution by decreasing time for data sending. Software improvements that demonstrate higher resolutions are already under development even with existing hardware only done by code optimization.

Figure 14. Send data time diagram



8.6 Software

The software is written in C language with several modules, but the most important files for proper operation of the STEVAL-ILL009V1 reference board are the following:

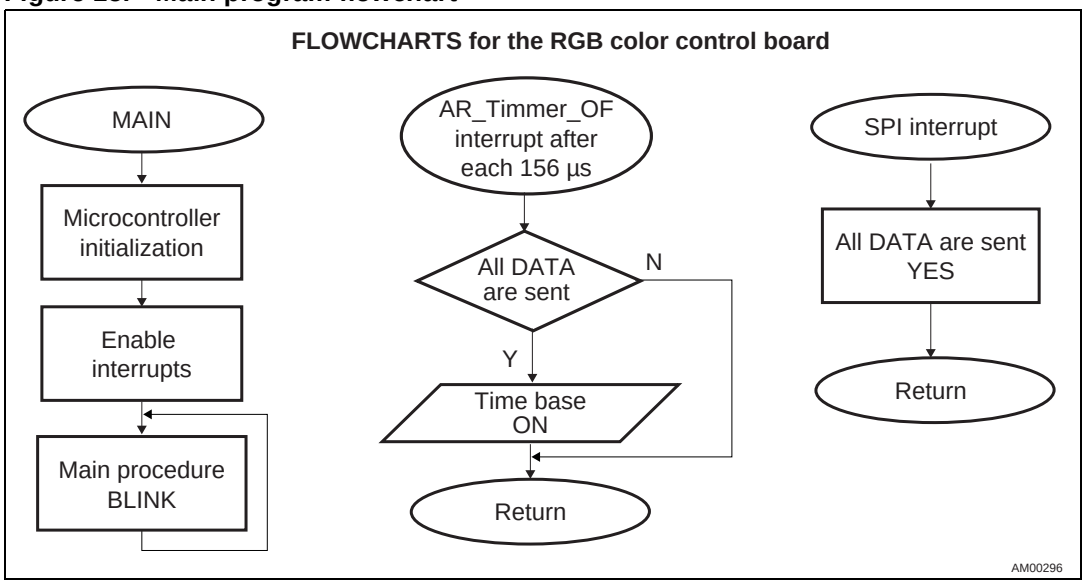
- main.c
- blink.c
- pwm_ar_timer_12bit.c
- spi.c
- adc_8bit.c

Note: The final code has slightly less than 1.4 KBytes and it will fit the ST7FLITE09 memory.

Main programming flowchart is shown in *Figure 15*. The program starts in main.c and initializes the microcontroller functions such as RC oscillator calibration, ports initialization, PWM AR timer setting for time base generation and SPI initialization (SPI clock frequency). Afterwards, the interrupts are enabled and the program runs in a never-ending loop in function blink.c.

Basically three interrupts can occur. First, an AR timer overflow interrupt, which generates a time base 156 µs for the software dimming in order to have precise brightness regulation. When this interrupt occur, the program checks if all data have been already sent through SPI or not. If not the data are missed and the program waits for next interrupt (156 µs), but it is only some kind of backup protection. The second interrupt is a SPI interrupt, which informs that data (single byte) have been already sent. The last interrupt is an external input interrupt, which detects that button was pressed.

Figure 15. Main program flowchart



The heart of the software is a blink function running in a never-ending loop. In the start part (*Figure 16*), the program waits until a PWM interrupt occurs during synchronization then the Counter_SW value is incremented. Generally, Counter_SW represents the number of levels for the software PWM modulation and in this case it is 64 (6-bit resolution) (described in detail in *Chapter 4*). The Brightness value set by potentiometer P2 is converted by the ADC to a value between 0 and 64 in each SW PWM period (each 10 ms / 100 Hz) and this value sets the PWM brightness on the Output Enable (OE) pin.

The next block checks the temperature every 2.55 seconds. This time is considered fast enough because, due to its inertia, there is no need to check the temperature any faster. If its value is higher than the limit, the PWM duty cycle is increased (0% duty cycle is full bright and 100% is no light) by one step. Therefore, the light is absolutely turned OFF after 163.2 seconds (64 levels times 2.55). If the temperature is lower then the limit, the PWM duty cycle starts decreasing down to maximum brightness (0%) and normal operation.

Time3 = 200 ms is used as a stabilization time for the DC-DC converter and linear regulator. The output capacitors C10 and C14 (*Figure 13*) should be charged first to avoid resetting the microcontroller (low voltage detector) and the flickering application due to the high load. At the end, the high power RGB LEDs are turned ON after 200 ms. This time delay occurs only once, when the application starts.

Figure 16. Blink function flowchart - first part

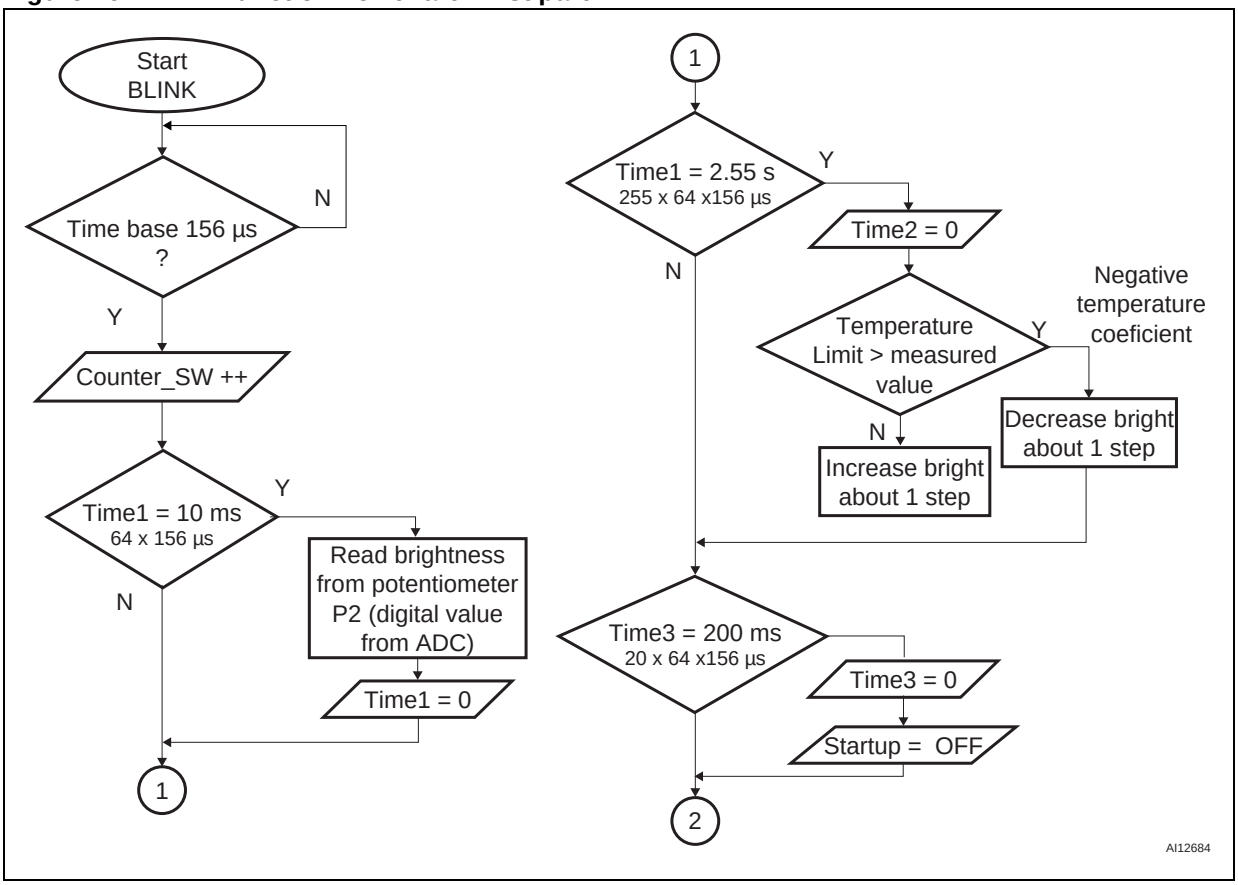


Figure 17 shows the second part of the blink function - the brightness setting (based on value read on P2 in first part) and mode selection (mode is selected by pressing button S2). MODE 1, MODE 2 and MODE 3 sets the brightness for the red, green and blue LEDs where the brightness level (0 to 64) is obtained from the potentiometer P1 after each SW PWM period (10 ms).

R, G & B elements could be set in single step with MODE 4 and MODE 5. This means the color is moving on a predefined curve as indicated in *Figure 18*. The difference between MODE 4 and MODE 5 is that MODE 4 is controlled by potentiometer P1 and MODE 5 is working automatically (simulating the P1 input). *Figure 18* shows how it works. The integer

number coming from ADC (potentiometer P1) has range from 0 to 252. This range is divided to six segments where always just one color is changed and two are constant (ON or OFF). Blue color is set if the potentiometer is in the left side (0 from ADC), because B = ON (blue), R = OFF (red) and G = OFF (green). If the value from ADC is increased to 42, the PWM of green color is decreased. In case ADC has value 42 the green is fully turned ON together with blue and red is OFF. The ADC value from 43 to 84 increases blue color (light is going down) and if ADC has value 84 only green LED is ON. In this way it is possible to move light through all basic colors. MODE 5 represents automatic color changing. The principle of the automatic color change is similar to manual color control, because the color level is not adjusted by potentiometer P1 (0-252), but automatically using the 156 µs time base generated by the auto-reload timer.

Note: In order to demonstrate the best lighting effects, the application automatically starts in MODE 5 - automatic color changing mode.

Figure 17. Blink function flowchart - second part

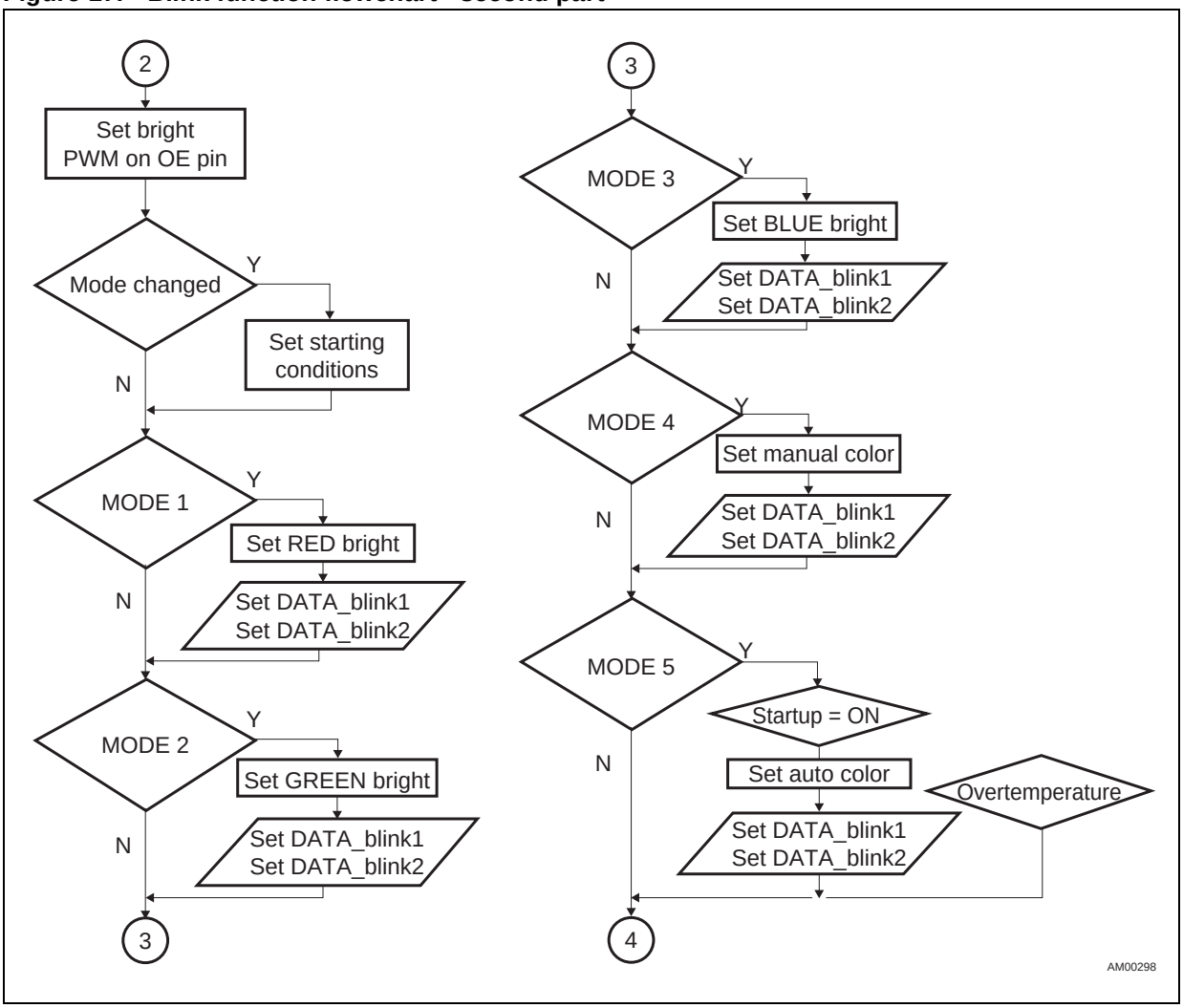
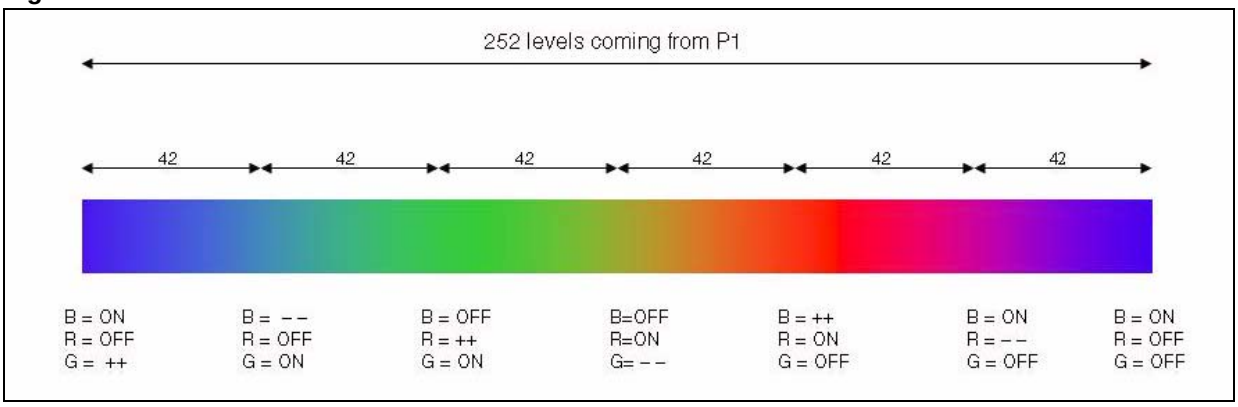
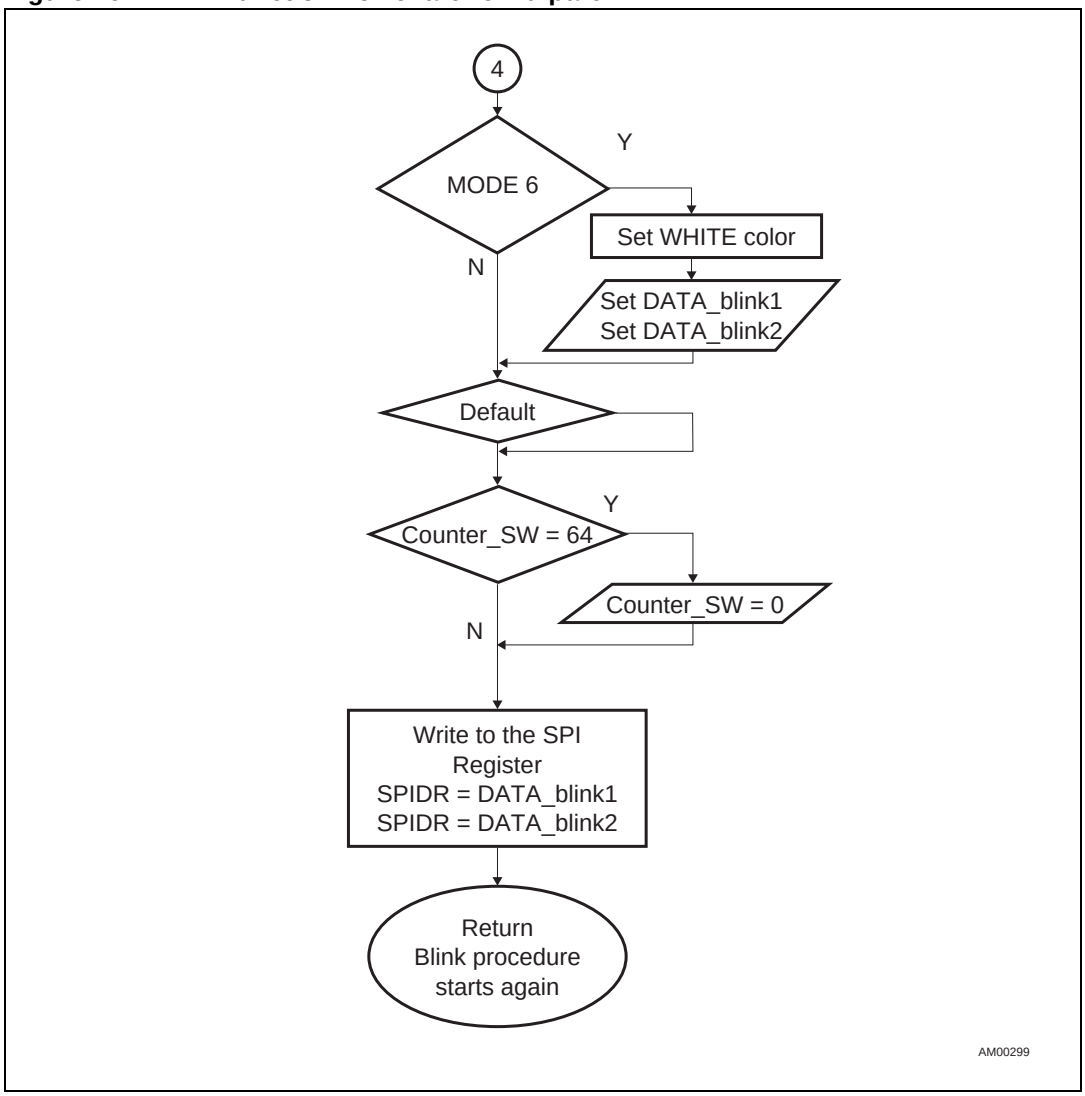


Figure 18. Manual color modulation



The last mode implemented is MODE 6, which is the simplest one - all the LEDs are turned ON, which produce the pure white color. *Figure 19* describes this last part.

Figure 19. Blink function flowchart - third part



9 STEVAL-ILL009V5 reference board

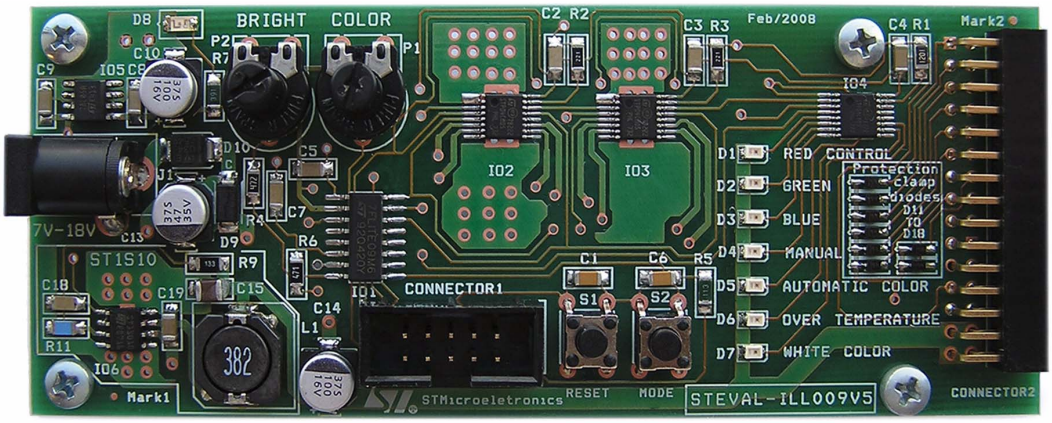
STEVAL-ILL009V5 reference board shown in *Figure 20* was designed in order to promote the new DC/DC converter ST1S10 and the new LED drivers STP04CM05 and STP08CP05. Thanks to the ST1S10 DC/DC converter the size of the inductor is decreased (compare *Figure 1* and *Figure 20*), efficiency improved and board size reduced. The STEVAL-ILL009V5 has 120 mm x 47 mm instead of 151 mm x 47 mm for the STEVAL-ILL009V1. The input voltage for the STEVAL-ILL009V5 ranges from 7 V to 18 V. The new LED drivers allow faster communications and higher output voltage. Other design features such as SW, brightness and color regulation, microcontroller, temperature protection, are identical on STEVAL-ILL009V1 and STEVAL_ILL009V5. Their features are described in *Chapter 8*.

The ST1S10 is a high efficiency step down PWM current mode switching regulator capable of providing up to 3 A of output current. The device operates with an input supply range from 2,5 V to 18 V. It operates either at a 900 kHz fixed frequency or can be synchronized to an external clock (from 400 kHz to 1,2 MHz). The high switching frequency allows the use of tiny SMD external components, while the integrated synchronous rectifier eliminates the need for a Schottky diode. The ST1S10 provides excellent transient response, and is fully protected against thermal overheating, switching over current and output short circuit. For more information see the ST1S10 Datasheet.

The STP04CM05 is a high-power LED driver and 4-bit shift register designed for Power LED applications. Four regulated constant current sources are designed to provide 80 - 400 mA current to drive high power LEDs. The STP04CM05 guarantees 20 V output driving capability, allowing users to connect more LEDs in series. The high clock frequency, 30 MHz, also satisfies the system requirements which include high volume data transmission. The STP04CM05 is backward compatible with the STP04CM596.

The STP08CP05 is a monolithic, low voltage, low current, power 8-bit shift register designed for LED panel displays. Eight regulated constant current sources are designed to provide 5 - 100 mA current to drive the LEDs, the output current setup time is 11 ns (typ), thus improving the system performance. The STP08CP05 guarantees a 20V output driving capability and high volume data transmission with clock frequency 30 MHz as well as the STP04CM05.

Figure 20. STEVAL-ILL009V5 reference board



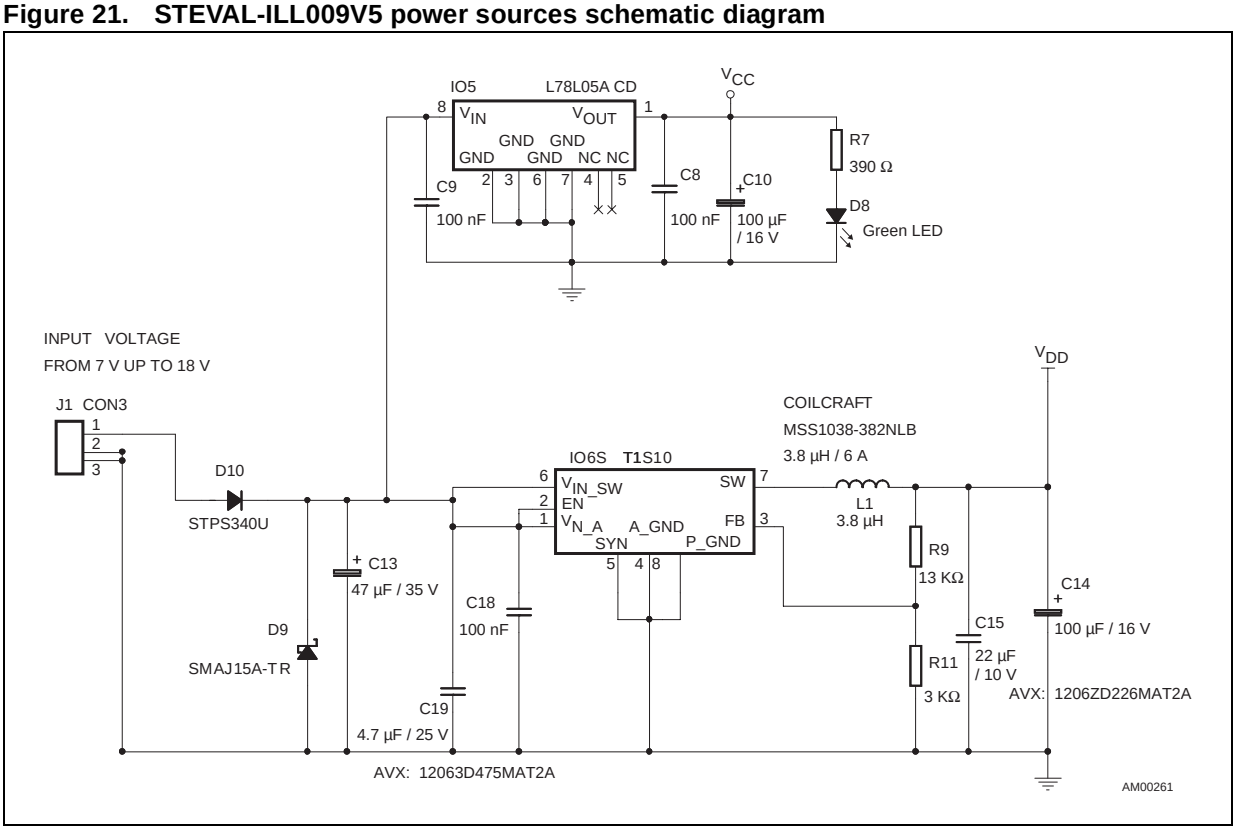
The STEVAL-ILL009V5 has the following differences to compare with the STEVAL-ILL009V1:

- 3 A at 4V DC/DC converter using the ST1S10 for input voltage range (7 V - 18 V)
- New improved LED drivers STP04CM05 and STP08CP05
- Input over voltage protection done by Transil (SMAJ15A-TR)
- Protection against input voltage reversion
- Board size reduced from 151 mm x 47 mm to 120 mm x 47 mm.

9.1 STEVAL-ILL009V5 schematic diagram

Figure 21 shows power supply schematic diagram. Basically, there are two parts. The first one is a very simple linear DC/DC converter using the L78L05ACD with output voltage 5 V used for supplying microcontroller and LED drivers. The second one is a step down converter using monolithic, synchronous, switching DC/DC converter ST1S10. The diode D10 protects the application against input voltage reversion and Transil D9 protects the ST1S10 against over voltage. The schematic diagram with LED drivers and microcontroller is not shown in this chapter, because it was already introduced in *Figure 12*. There is only small difference, because the new LED drivers STP04CM05 and STP08CP05 instead the STP04CM596 and STP08CL596 are used on the STEVAL-ILL009V5.

Figure 21. STEVAL-ILL009V5 power sources schematic diagram



9.2 Bill of material

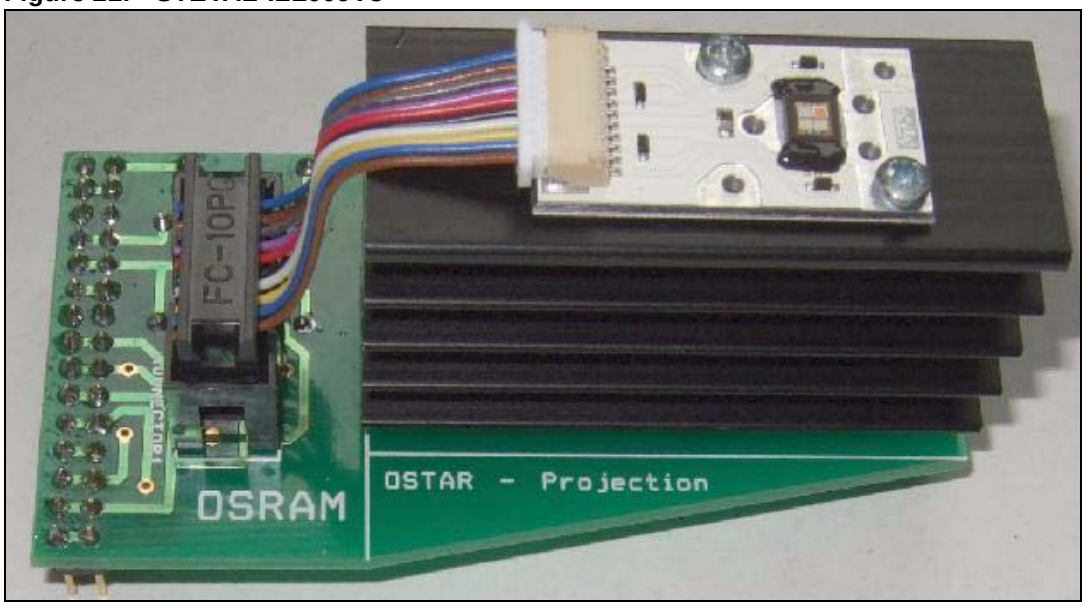
Table 4. STEVAL-ILL009V5 bill of material

Item	Quantity	Reference	Part	Note	Ordering code
1	1	CONNECTOR1	ICC	10 PIN	
2	1	CONNECTOR2	CON	30 PIN	
3	2	C1,C6	10 nF	Ceramic SMD1206	
4	8	C2, C3, C4, C5, C7, C8, C9, C18	100 nF	Ceramic SMD1206	
5	2	C10, C14	100 µF / 16 V	Electrolytic SMD	
6	1	C13	47 µF / 35 V	Electrolytic SMD	
7	1	C15	22 µF / 10 V	Ceramic SMD1206	AVX:1206ZD226MAT2A
8	1	C19	4.7 µF / 25 V	Ceramic SMD1206	AVX:12063D475MAT2A
9	7	D1, D2, D3, D4, D5, D6, D7	Red LED	OSRAM red LED Mini TOPLED	LS M670-H2K1-1
10	1	D8	Green LED	SMD LED 1206	
11	1	D9	SMAJ15A-TR	ST - Transil	SMAJ15A-TR
12	1	D10	STPS340U	ST - diode	STPS340U
13	8	D11, D12, D13, D14, D15, D16, D17, D18	BAT46	ST - Schottky diode	BAT46JFILM
14	1	IO1	ST7FLITE09	ST - microcontroller	ST7FLITE09Y0M6
15	2	IO2, IO3	STP04CM05	ST - LED driver	STP04CM05XTTR
16	1	IO4	STP08CP05	ST - LED driver	STP08CP05TTR
17	1	IO5	L78L05	ST - voltage regulator	L78L05ACD
18	1	IO6	ST1S10	ST - DC/DC converter	ST1S10PHR
19	1	J1	CON3	Input connector	
20	1	L1	3.8 µH / 6 A	Coilcraft inductor	MSS1038-382NLB
21	2	P1, P2	10 KΩ	Pot. with axis	
22	1	R1	3 kΩ	SMD resistors 1206	
23	2	R2, R3	220 Ω	SMD resistors 1206	
24	1	R4	4.7 KΩ	SMD resistors 1206	
25	1	R5	10 KΩ	SMD resistors 1206	
26	1	R6	470 Ω	SMD resistors 1206	
27	1	R7	390 Ω	SMD resistors 1206	
28	1	R9	13 KΩ	SMD resistors 1206	
29	1	R11	3 KΩ	SMD resistors 1206	
30	2	S1, S2	Switch	Switch	

10 STEVAL-ILL009V3 load board

The STEVAL-ILL009V3 demonstration board is shown in *Figure 22*. This board should be connected through the 30-pin connector to the STEVAL-ILL009V1 control board to be able to show the light effect with the board. The OSTAR projection module (refer to *Chapter 12*, point *1*), used as light source, has a maximum forward current 700 mA. The NTC resistor is directly assembled on the OSTAR module. As the power of the module is above 10 W the heatsink had to be designed in order to keep the temperature in range. The biggest advantage of the OSTAR module is that red, green and blue LEDs are in the same package, very closely assembled and therefore color effect is better than with three separate LEDs.

Figure 22. STEVAL-ILL009V3



10.1 Schematic description

The schematic of the STEVAL-ILL009V3 is shown in *Figure 23*. As described, the constant current flowing through each channel is set to 350 mA, but because 700 mA is needed to drive the OSTAR module, two outputs are connected in parallel (*Figure 23*). Resistor R4 represents together with the NTC resistor the voltage divider for the temperature sensing (described in detail in *Chapter 8.5.2*). The software has a preset temperature limitation 50 °C for Golden DRAGON LEDs using STLM20 temperature sensor, which means a voltage of 1.263 V on the ADC. The NTC has a resistance of 1588 Ω at72 °C and the voltage coming from resistor divider to the ADC is exactly 1.263 V. So, the default temperature limit for the OSTAR module is 72 °C, but it can be very easy changed by software. The HB LEDs are supplied from the DC/DC converter 4 V at 3 A.

The maximum green and blue LEDs forward voltage is 4 V, but the red forward voltage is 3.4 V. If 3.4 V is around red LED, the rest of the supply voltage (4 V) must be on the driver (0.6 V) causing a power loss and therefore the design includes the connection of resistors R1, R2 and R3 to decrease power dissipation on LED drivers and move these losses to the resistors.

Equation 14

$$V_R = V_d - V_{F_RED_MAX} = 4 - 3.4 = 0.6V$$

Equation 15

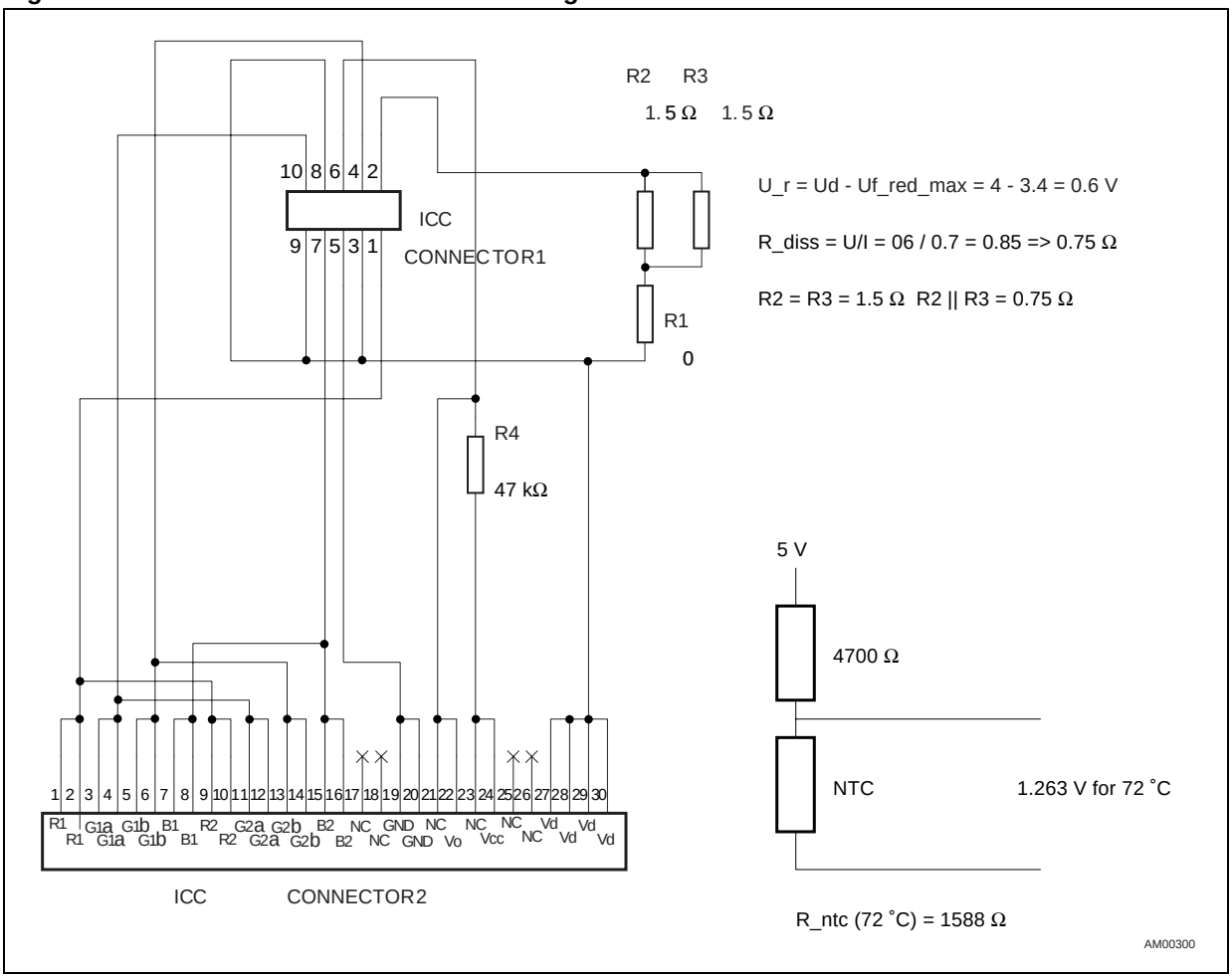
$$R_{diss} = \frac{V_R}{I_{RED_LED}} = \frac{0.6}{0.7} = 0.85\Omega$$

10.2 Bill of material

Table 5. STEVAL-ILL009V3 bill of material

Item	Quantity	Reference	Part	Note	Ordering code
1	1	OSTAR projection module		OSRAM OSTAR Projection Module	LE ATB A2A
2	1	Cable with connector		10 lines cable	SHR-10V-S-B -> JST
3	1	Heatsink		SEMIC Trade	8150/50/N
4	1	Connector1		10 pins	
5	1	Female Connector1		10 pins	
6	1	Connector2		30-pin connector	
7	1	R1	0		
8	2	R2, R3	1.5 Ω	Through-hole 0.6 W	
9	1	R4	4.7 kΩ	Through-hole 0.6 W	

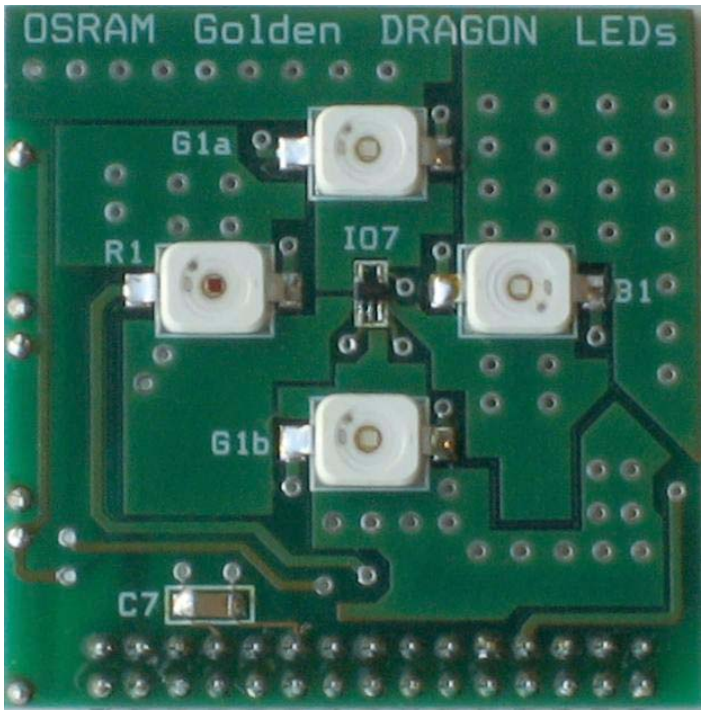
Figure 23. STEVAL-ILL009V3 schematic diagram



11 STEVAL-ILL009V4 load board

The STEVAL-ILL009V4 demonstration board is shown in *Figure 24*. This board is an option to the STEVAL-ILL009V3. As a light source, there are four Golden DRAGON LEDs (refer to *Chapter 12*, point *2*) used with a maximum forward current of 350 mA. As described in *Chapter 8*, the STEVAL-ILL009V1 can drive eight Golden DRAGON LEDs. To demonstrate the driving capability of the STP04CM596, only four LEDs are used on the load board. In fact, this means that one STP04CM596 driver is not used. The STLM20 temperature sensor is assembled in the middle of the LEDs to protect against overheating (as described in *Section 8.5*).

Figure 24. STEVAL-ILL009V4



11.1 Schematic description

The schematic of the STEVAL-ILL009V4 is shown in *Figure 25*. The temperature limitation of the Golden DRAGON LEDs is set to 50 °C on this board. Similar to the STEVAL-ILL009V3, resistors R4, R5 and R6 are used to decrease the power dissipation on LED driver. The resistor value is calculated using the following equation:

Equation 16

$$V_R = V_d - V_{F_RED_MAX} = 4 - 2.6 = 1.4V$$

Equation 17

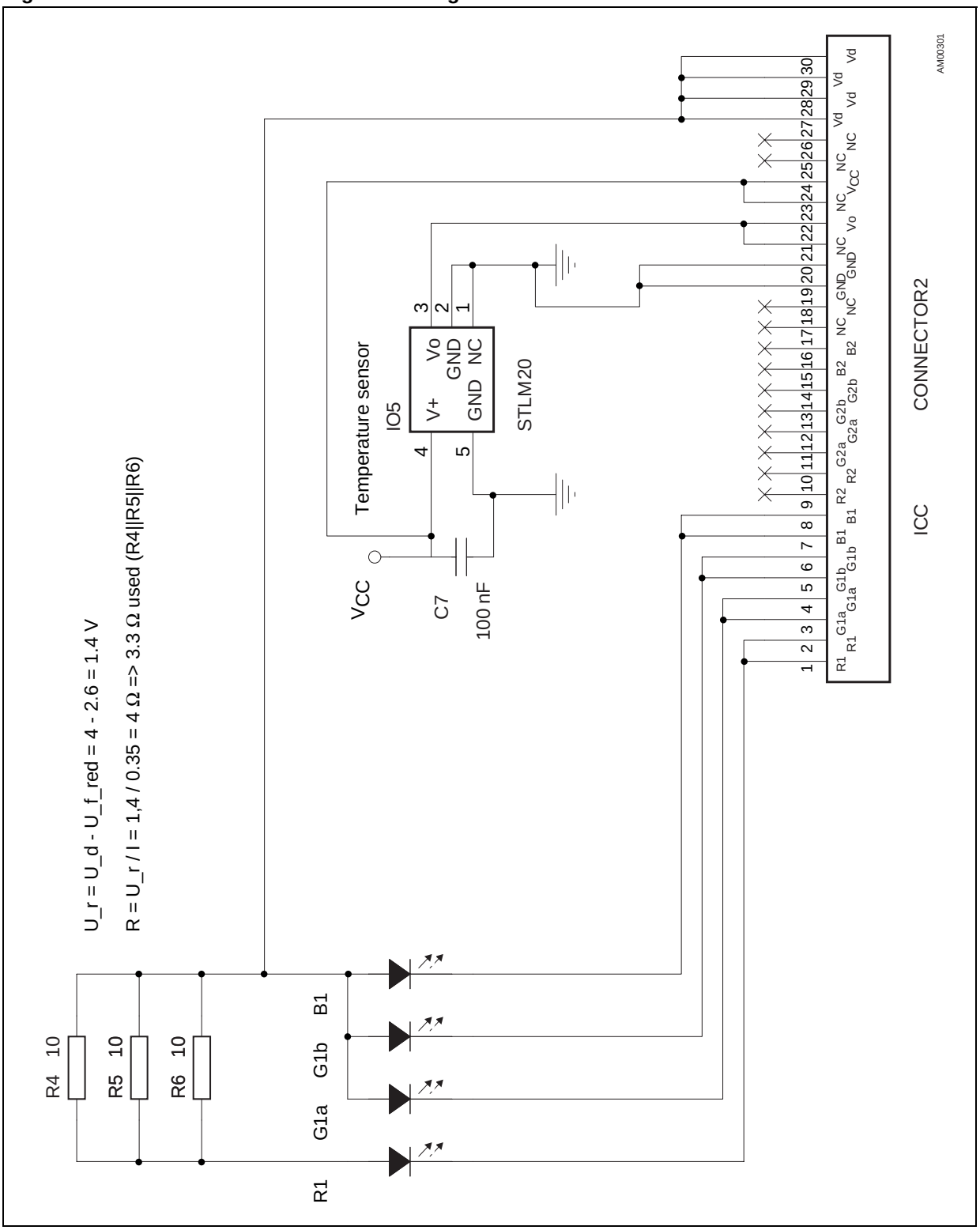
$$R = \frac{V_R}{I_{RED_LED}} = \frac{1.4}{0.35} = 4\Omega$$

11.2 Bill of material

Table 6. STEVAL-ILL009V4 bill of material

Item	Quantity	Reference	Part	Note	Ordering code
1	2	G1a, G1b	LTW5SM HZ-3	OSRAM Golden DRAGON Green LED	Q65110A5876
2	1	R1	LRW5SM HY-1	OSRAM Golden DRAGON Red LED	Q65110A4386
3	1	B1	LBW5SM FX-3	OSRAM Golden DRAGON Blue LED	Q65110A4396
4	1	C7	100 nF / 50 V	Ceramic SMD1206	
5	3	R4, R5, R6	10 Ω	Through-hole resistor	
6	1	IO7	STLM20	ST temperature sensor	STLM20W87F
7	1	Connector2		30-pin connector	

Figure 25. STEVAL-ILL009V4 schematic diagram



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13 Revision history

Table 7. Document revision history

Date	Revision	Changes
3-May-2007	1	Initial release.
23-Sep-2008	2	Updated *Introduction*, *Chapter 12*, *Figure 2* to *Figure 10*, *Figure 12*, *Figure 13*, *Figure 15* to *Figure 17*, *Figure 19*, *Figure 23* and *Figure 25*, added *Figure 21* and *Chapter 9*.

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